Millimeter and Submillimeter Interference Spectroscopy Techniques†

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An interference spectrometer operating on the principle demonstrated by Strong (ref. 1) and others (ref. 2 and 3) has been constructed at Georgia Tech. This instrument, which is shown schematically in Figure 1, has been designed to operate in the 40 GHz to 3000 GHz frequency region with maximum resolution ranging from about 250 in the lower frequency region to 500 at submillimeter wavelengths. Figure 2 is a photograph of the spectrometer with its accompanying vacuum chamber.

Experiments will be described in which this instrument is used to explore the properties of water vapor absorption lines and possibilities for dielectric constant measurements, as well as to evaluate millimeter and submillimeter broad-band noise sources and filters.

Preliminary experiments were performed in the 40 to 80 GHz frequency band. The detector used at these frequencies was an evacuated waveguide barretter and the noise source most frequently used was a waveguide mounted low-pressure neon plasma with an effective temperature in the RG-98/u waveguide band of 14,700 deg K, according to the manufacturer.* Other noise sources tested in this region were of the extended area types which included a positive column neon tube inserted in a circular horn, a similarly mounted argon tube, and a 250-watt mercury arc lamp. The neon sources were found to be superior to other sources tested, and it was

†Supported by NASA Grant NSG-258.

*Roger White Electron Devices type GNW-18-V found that impedance matching or emissivity was improved by a few percent when the tube was mounted in waveguide so that virtually all of the energy was propagated in a single spatial mode.

The potential use of the interference spectrometer as a tool for the measurement of dielectric properties of solids was explored in the 45 GHz to 65 GHz frequency region. The method used for these experiments was to record interferograms with a dielectric sample of known thickness in the source beam and removed. The difference of the spectra calculated from these interferograms was used to obtain a spectrum of energy lost due to insertion of the dielectric. The cyclic variation caused by interference reflections between the two surfaces of the sample was then used to calculate the relative dielectric constant. Some analyses have also been made to learn more about loss tangent from the data with unsatisfactory results; the difficulties are similar to those encountered in making loss tangent measurements in free space at centimeter wavelengths.

In extending the operating frequency to submillimeter wavelengths, the evacuated barretter was replaced by a liquid-helium cooled germanium bolometer and again a number of noise sources were tested. At center frequencies above 300 GHz best results were obtained with the mercury arc lamp and a $1350^{\circ}$ K crucible type oven. The spectra from these noise source measurements are shown in Figure 3, over a frequency range from 200 to 650 GHz and under normal atmospheric conditions. The rapid loss in power above 500 GHz is due, in addition to significant water vapor absorption near 550 GHz, to insertion of a filter consisting of two layers of 0.006" thick black photographic paper, and the loss below 300 GHz is attributed to the following mechanisms: multiple

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reflections in the 0.0035" thick mica vacuum window used on the detector input horn, loss of power transmitted by high-order modes cut off in the detector waveguide, and reduction in efficiency of the resonant beamsplitter.

Some measurements have been made in the 500 GHz to 1500 GHz frequency region to demonstrate potential use of the instrument for measuring gaseous absorption lines. The water vapor absorption lines as they occur at normal room temperature, pressure and humidity with a 2 meter effective path length are seen clearly in Figure 4 at 557, 753, 987, 1098-1113, 1161, 1213-27, and 1407 GHz. It also appears that the two lines at 641 GHz, the three lines near 860 GHz and the four lines from 1310-30 GHz are visible. The 1320 GHz cluster are predicted by Ghose and Edwards (ref. 4) to be comparable in magnitude to the 550 GHz line and this is seen to be the case although the line "skirts" are masked by the more intense absorption on either side. Reference 4 predicts eighteen lines from 1000-1250 GHz. These are masked by the very intense lines mentioned above and by the 30 GHz resolution at which this spectrum was taken. With greater resolution the absorption lines would be somewhat greater in magnitude and slightly narrower in bandwidth than shown in Figure 4. Sheppard (ref. 5) calculated the absorption curve to 1000 GHz on the basis of a 0.2 $cm^{-1}$ shape factor and the Van Vleck-Weisskopf equation. The agreement in the observed values of attenuation in the windows near 600 and 680 GHz is very close to the calculated. Sheppard's curve did not consider values of the lower rotational quantum number $J > 6$, hence the windows observed near 825 and 910 GHz are, as would be expected, greater than calculated. It may be noted that the 753 GHz line is comparable in strength to the 557 GHz lines as calculated (ref. 4 and 5) rather than as observed by Iaroslavski and Stanevich (ref. 6). There appears to be a line near 1040 GHz which is not predicted considering transitions for $J \leqq 12$ (ref. 4). This remains unexplained at the writing. The attenuation curve of Figure 4 was calculated taking the difference in spectra which were obtained at normal room atmospheric conditions and at a pressure of several millimeters. It is not expected that a better vacuum would cause appreciable change in the line skirts or in the weaker lines although the peak attenuation of strong lines may be several decibels greater than shown.

References


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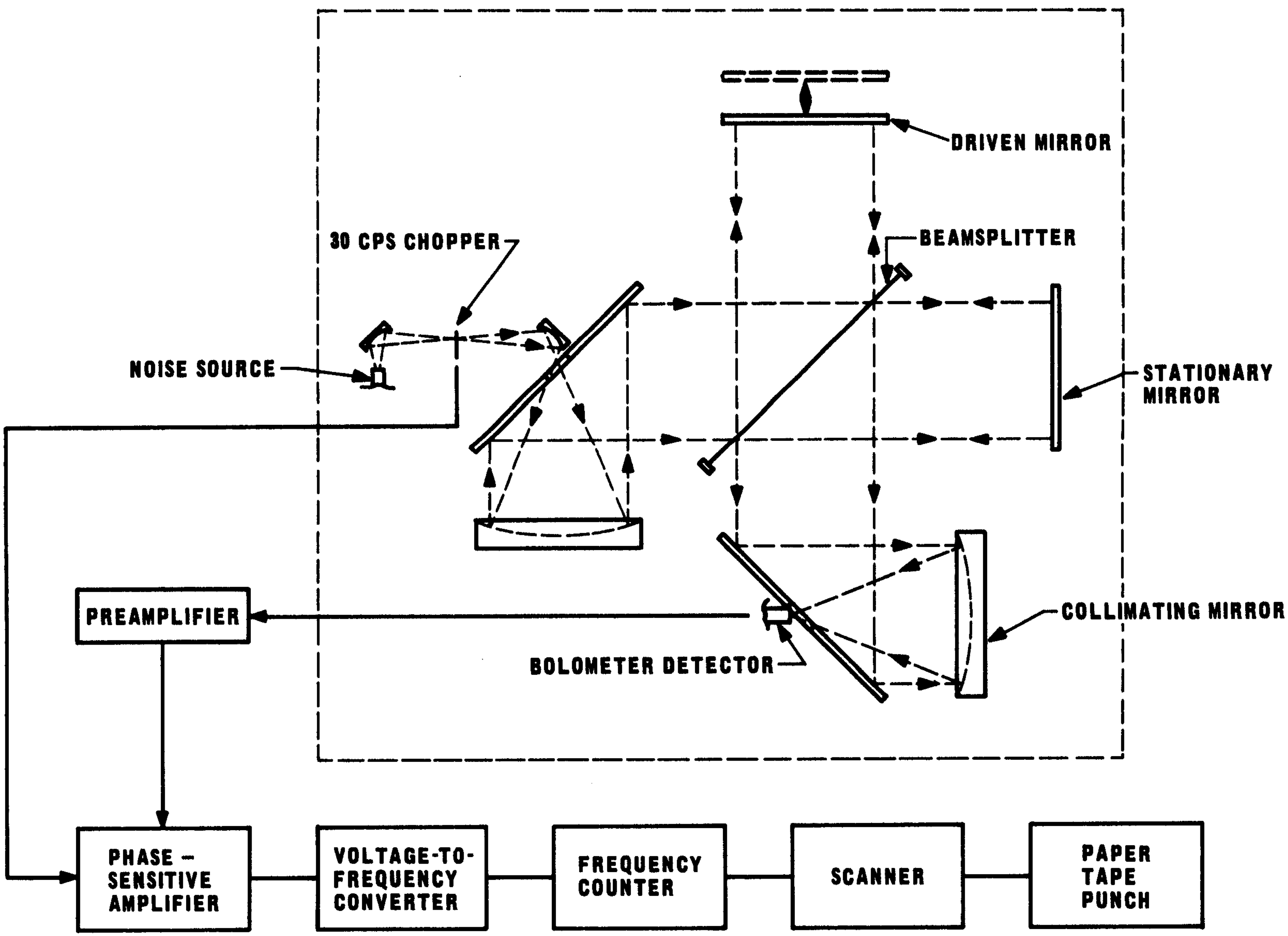


Figure 1. Schematic of Spectrometer and Block Diagram of Output and Data Recording Equipment.

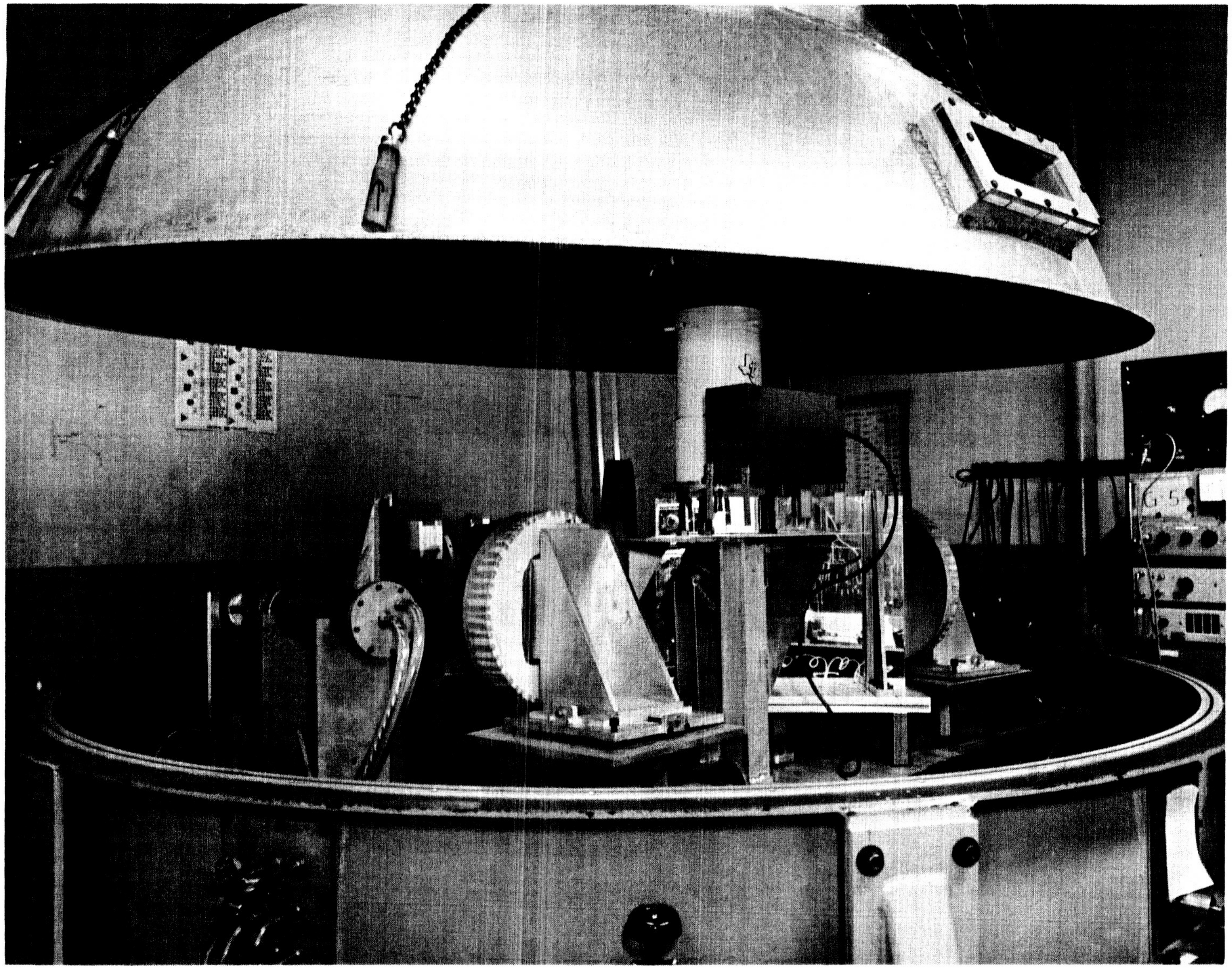

Figure 2. Photograph of the Spectrometer in Vacuum Chamber.

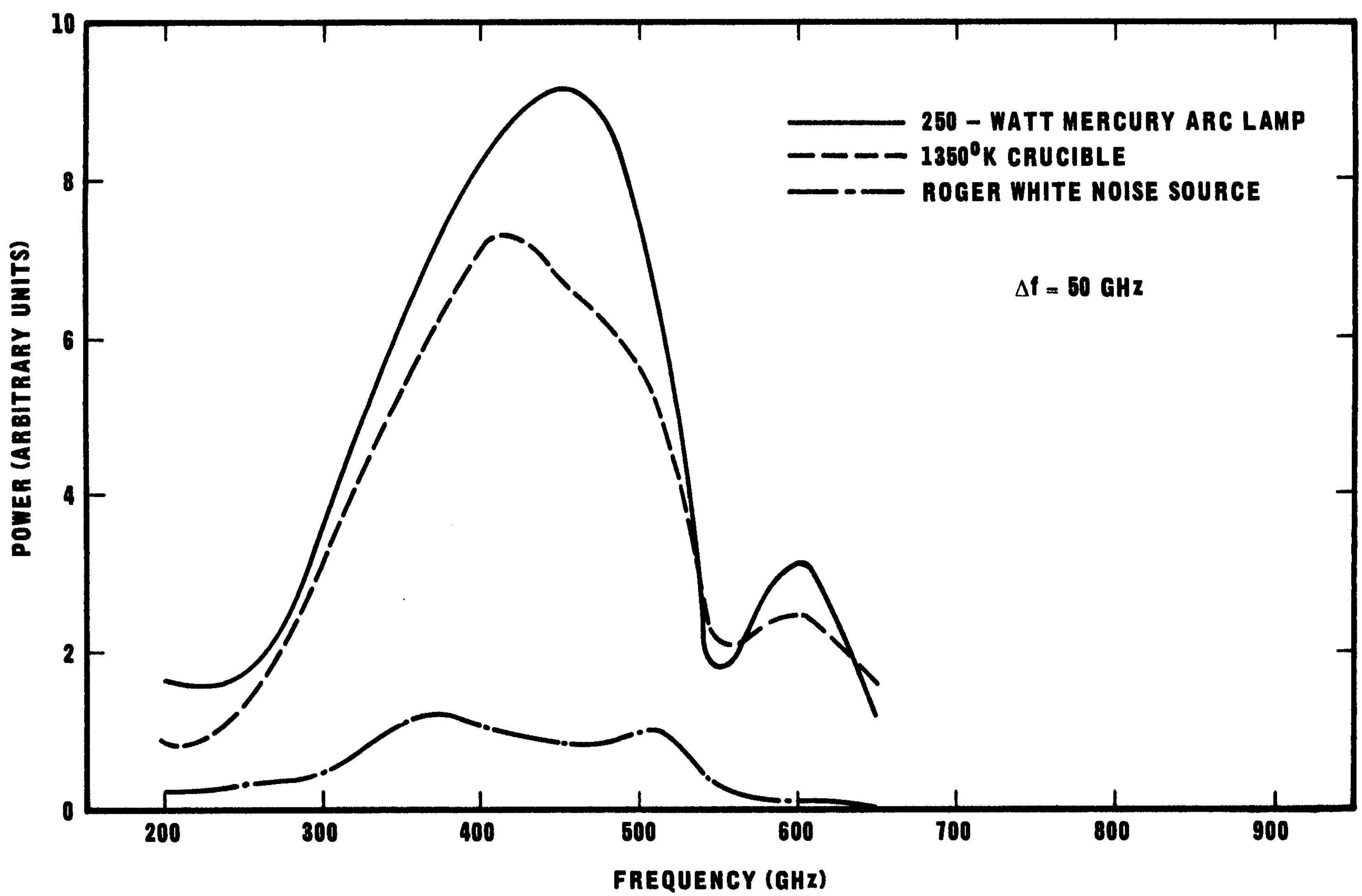


Figure 3. Noise Source Measurements.

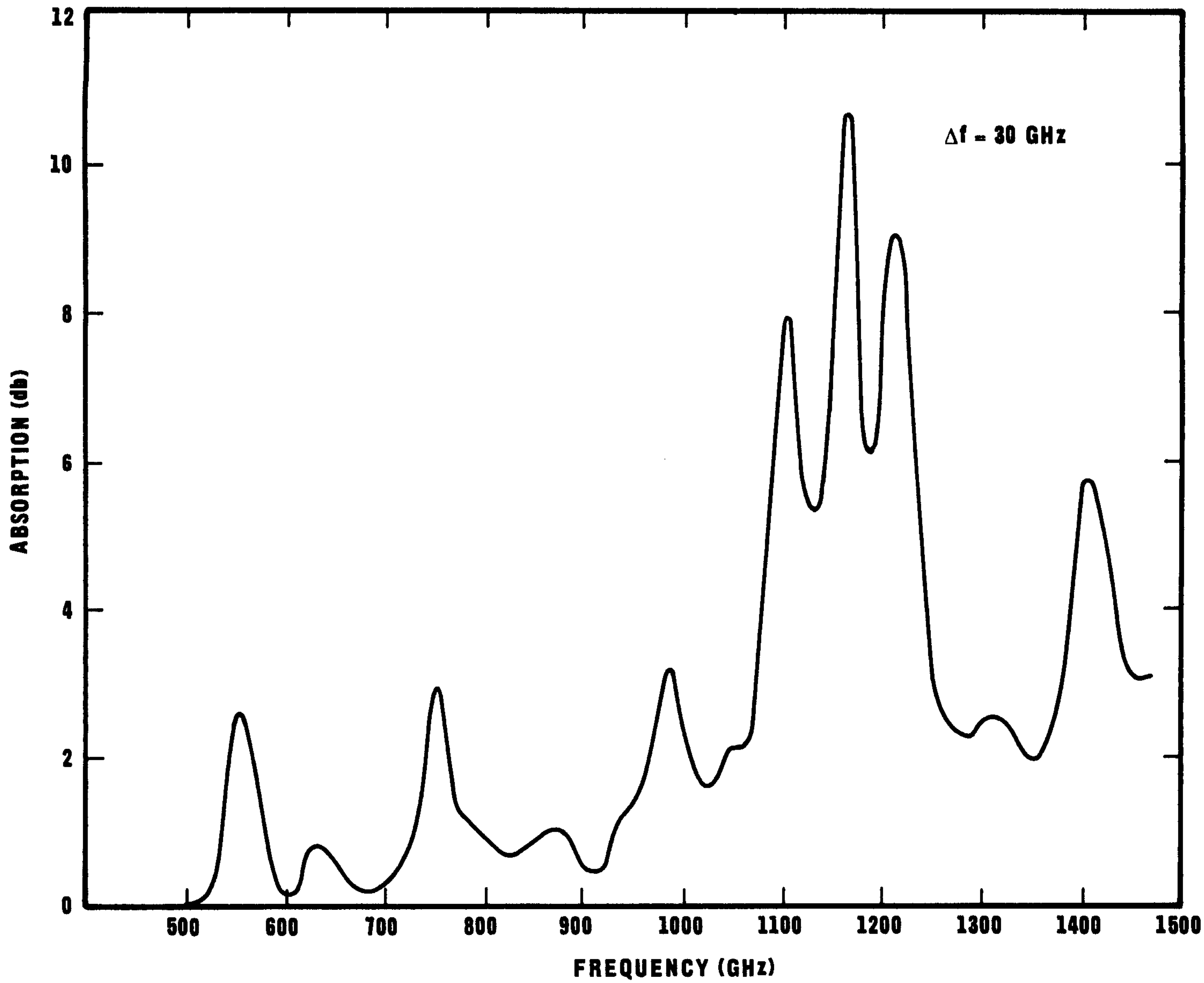


Figure 4. Plot of Water Vapor Asborption Over Two Meter Effective Path at Room Temperature, Pressure, and Humidity.